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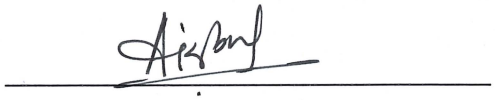
I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering (Hons.) Manufacturing Engineering.



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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at University Malaysia Pahang or any other institutions.

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Date : 07 June 2017

INVESTICATION OF THE MECHANICAL PROPERTIES OF Al-Al_2O_3-Gr HYBRID COMPOSITE FABRICATED BY POWDER METALLURGY

KELVIN LEE KHAI MENG

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ABSTRAK

Pembangunan MMC Hibrid telah mencipta revolusi baharu dalam penyelidikan bahan. MMCs memainkan peranan penting dalam aplikasi struktur seperti cakera brek kereta. Antara jenis MMCs yang berbeza, MMCs berasaskan Al mempunyai ciri-ciri mekanikal yang lebih baik kerana mereka boleh menggabungkan sifat yang berbeza. Dalam penyelidikan ini, MMC Hibrid, Al-Al_2O_3-Gr mempunyai sifat mekanikal yang lebih baik berbanding dengan Al asas. Penggunaan cakera brek memerlukan bahan yang bercirikan kekuatan mekanikal dan daya tahan friksion. Bahan monolitik tidak dapat memberikan semua sifat-sifat yang diperlukan untuk aplikasi tertentu. MMC Hibrid dibuat dengan Al_2O_3 dan Gr dapat memberikan kekuatan yang lebih tinggi dan daya tahan friksion. Al_2O_3 mampu meningkatkan kekuatan komposit dan Gr meningkatkan ciri friksion kerana Gr merupakan pelincir pepejal. Di samping itu, kehomogenan zarah dalam MMC merupakan kriteria penting untuk mempengaruhi ciri-ciri mekanikal bahan. Dalam penyelidikan ini, Al- Al_2O_3-Gr MMC Hibrid dihasilkan melalui kaedah metalurgi serbuk kerana kaedah ini dapat menghasilkan seragam struktur yang lebih baik berbanding dengan proses pembuatan yang lain. Oleh itu, terdapat tiga objektif utama dalam penyelidika ini, pertama, untuk fabrika MMC Hibrid, Al-Al_2O_3-Gr dengan kaedah metalurgi serbuk, kedua, untuk menyiasat sifat-sifat mekanikal Al-Al_2O_3-Gr MMC Hibrid tersebut. Dan ketiga, untuk mengoptimumkan sifat-sifat mekanikal hibrid MMC, Al-Al_2O_3-Gr tersebut untuk menggunakan bahan ini dalam aplikasi struktur. Dalam kaedah metalurgi serbuk, pertama sekali, serbuk Al, Al2O3 dan Gr dicampur dengan sama rata sebelum dineruskan dengan proses pemadatan. Kedua, proses pemadatan dilakukan dengan menggunakan mesin hidraulik panas dan kemudiannya menghasilkan padatan hijau dan suhu ditetapkan pada 150 °C selama 1.5 minit. Kemudiannya, padatan hijau akan disinter selama 4 jam pada suhu 600 °C dengan kadar pemanasan 5 °C/min. Akhir sekali, pengisaran dan penggilap telah dilakukan bagi melicinkan permukaan spesimen. Pada masa yang sama, ketumpatan, ujian kekerasan, dan ujian tegangan dijalankan Akhir sekali, mikrostruktur setiap spesimen juga diperhatikan di bawah mikroskop logam. Oleh itu, dalam kajian ini, didapati bahawa ketumpatan MMC hibrid spesimen selepas disinter menurun berbanding ketumpatan teori kerana peningkatan keliangan. MMC hibrid menunjukkan nilai kekerasan yang lebih tinggi berbanding dua bahan lain. Gr adalah elemen yang sangat keras. Oleh itu, Gr meningkatkan kekerasan MMC hibrid.

ABSTRACT

The development of Hybrid Metal Matrix Composite (Hybrid MMC) has created a new revolution for related material's research. This makes the MMCs plays significant role in structural application such as brake disc of automobiles. Among different types of MMCs, Al based MMCs have extensive mechanical strength and fatigue properties as they can combine different properties. In this project, the Hybrid MMC, Al-Al_2O_3-Gr has better mechanical properties as compared to their base Al. The application of break disc requires material which has good performance in mechanical strength and wear properties. A singly monolithic material could not provide all the necessary properties for a particular application. The Hybrid MMC made with Al_2O_3 and Gr able to provide higher strength and wear resistance properties. Al_2O_3 increase the strength of composite and Gr increase the wear resistance as Gr is considered a solid lubricant. In addition, the homogeneity of the particles in the composite are an important criteria to ensure the properties of the MMC. In this research, Al-Al_2O_3-Gr Hybrid MMC was fabricated by powder metallurgy method because this method are consider of producing a more uniform distributed structure between the particles in the composite as compare to other manufacturing processes. Hence, there are three main objectives in this research, to fabricate the Al-Al_2O_3-Gr hybrid MMC using powder metallurgy, to investigate the mechanical properties of Al-Al_2O_3-Gr hybrid MMC and to optimize the mechanical properties of Al-Al_2O_3-Gr hybrid MMC to use this material in the structural application. In powder metallurgy method, first the Al, Al_2O_3 and Gr powders are first mixed evenly before carry on with compaction. Secondly, compaction process is performed using the hot pressing machine which then produce the green compact and the temperature were fixed at 150°C for 1.5 minutes. The green compact are then, sintered for 4 hours at 600°C with heating rate of 5°C/min. Finally, grinding and polishing has been performed to enhance the specimen surface. Simultaneously, the density, hardness test, and tensile test were carried out. Finally, the microstructure of each specimens were also observed under the metallurgical microscope. Hence, in this research, it is found that the density of the hybrid MMC specimens after the sintering process is decreased compared to the theoretical density due to the increase of porosity. The hybrid MMC showed higher hardness value as compared to other two materials. The Gr is a very hard element. Therefore, addition of Gr significantly increased the hardness of the hybrid composite.

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LIST OF SYMBOLS

$=$	Equivalent
$\approx$	Approximate
^{o}C	Celsius
$\times$	Multiply
π	Pi number
ρ	Rho

LIST OF ABBREVIATIONS

Al_2O_3	Aliminium Oxide
Al	Aluminium
AMC	Aluminium Metal Matrix Composite
C	Carbon
CFAMC	Continuous Fibre Reinforced Aluminium Metal Matrix Composite
CIP	Cold Isostatic Pressing
CMC	Ceramic Matrix Composite
CVD	Chemical Vapour Deposition
Gr	Graphite
HIP	Hot Isostatic Pressing
MFAMC	Mano Filament Aluminium Metal Matrix Composite
MMC	Metal Matrix Composite
PAMC	Particle Reinforced Aluminium Metal Matrix Composite
PMC	Polymer Matrix Composite
SFAMC	Short Fibre Reinforced Aluminium Metal Matrix Composite
SiC	Silicon Carbide
TiB_2	Titanium Boride

CHAPTER 1

INTRODUCTION

1.1 Introduction

Metal Matrix Composite (MMC) play significant role in structural applications. MMC is a composite made up of two or more types of material. Most importantly the matrix is metal. These MCs have extensive mechanical and fatigue properties as compared to their monolithic materials. Among different types of MMCs, Al based hybrid MMCs show better structural performance as they can combine different properties. In this research, Al_2O_3-Gr MMC is a composite with aluminium, Al matrix and aluminium oxide, Al_2O_3 and Graphite, Gr reinforcements respectively inhibiting hardening and solid lubricant. Al alloy MMC is widely used in aerospace, automotive and various engineering science applications such as industrial, electrical and thermal production. This is because modified metal has extensive mechanical properties compared to the individual base metal. MMC substitution vary widely and higher strength, tribology property or damping capacity and improves in modulus, as well as it reduced thermal expansion or density, and the cost competitiveness ("<O'Donnell, Looney - 2001 - Production of aluminium matrix composite components usingrconventional PM technology.pdf>,").

Besides that, there are few processes in fabricating MMCs such as liquid fabrication methods, solid state fabrication methods and many more. Others production-processes such as continuous binder-powder coating, mechanical alloying squeeze casting technology, metal injection molding friction stir process, etc. are used by researchers for fabricating the MMC. Fabrication of MMCs has reduced cost to an acceptable level compared to those processed by powder metallurgy and spray casting process (Kandpal, Kumar, & Singh, 2014).

However, in this thesis, the powder metallurgy method is selected to fabricate the Al_2O_3-Gr MMC. Powder metallurgy is remarkable development due to its ability to provide more uniform dispersion of composites in the MMC (Iacob, Ghica, Buzatu, Buzatu, & Petrescu, 2015). The uniformity distribution of Al_2O_3 and Gr reinforcements is important to the composite because it avoid the MMC from crack initiation in the early stage of material failure. In the recent research, only powder metallurgy fabrication is able to prevent this occurrence in the MMCs.

The fabrication of MMCs with powder metallurgy method include compaction process and sintering process which these affects the mechanical properties of the MMC respectively. The compaction process maybe hot isostatic pressing or cold isostatic pressing. Meanwhile, the sintering is a process of applying heat to the green compact to enhance the MMC. Compaction process is important in determining the particles arrangement in the MMC while the sintering process, the sintering temperature affect the porosity of the MMC. Hence, the optimum parameters of both compaction load and sintering temperature has great consideration on yielding the MMC with extensive mechanical and tribology properties.

1.2 Problem Statement

Al-Al_2O_3-Gr MMC is an improved composite which its mechanical properties are enhanced in term of its hardness, tensile strength, yield strength, modulus and tribological properties compare to the Al base metal reinforced with aluminium oxide Al_2O_3 and graphite, Gr components. The hardness of the hybrid composite decreases with the introduction of Gr particles to the Al and its alloy. Additional of Al_2O_3 reinforcement composite increased the hardness of the hybrid composites of its Al base metal. This hybrid composite is characterized by the hard nature of Al_2O_3 particles. To overcome this occurrence, the Al_2O_3 hard ceramic particles is added which it is capable acting as the obstacles to the movement of dislocation. Hence, this limits the deformations and resists the penetration and cutting of slides on the surface of the hybrid composite (Baradeswaran & Elaya Perumal, 2014).

The uniformity or homogeneity dispersion of particles of Al_2O_3 and Gr of hybrid MMC in matrix of Al is an important factor affecting the mechanical and tribological properties of the fabricated composite (IACOB, POPESCU, & BUZATU, 2013). The-

fabrication of the hybrid composite using powder metallurgy is the most effective method that ensuring the powder particles of the base metal Al reinforcement- Al_2O_3 and Gr are sufficiently penetrate during the interaction in the bonding between the powder particles. Hence, the distribution and penetration of the composite with its great relationship on the sintering temperature in the sintering process able to produce a good hybrid composite with optimal mechanical and tribological properties (O'donnell & Looney, 2001).

1.3 Objectives

The objectives of this thesis are:

i. To fabricate the Al-Al_2O_3-Gr hybrid MMC using powder metallurgy method.

ii. To investigate the mechanical properties of Al-Al_2O_3-Gr hybrid MMC.

iii. To optimize the mechanical properties of Al-Al_2O_3-Gr hybrid MMC to use this material in the structural application.

1.4 Scope of Research

i. Fabrication the Al-Al_2O_3-Gr hybrid MMC using powder metallurgy.

ii. Investigation the mechanical properties of the hybrid MMC.

iii. Optimization the mechanical properties of the hybrid MMC.

1.5 Thesis Organization

This thesis containing five chapters. The first chapter introduced on the introduction, problem statements, objectives, research scope and the organization of the thesis. Furthermore, in Chapter 2, it explained the literature review of others researchers on the method and mechanical investigations of the hybrid MMC. In Chapter 3, it described on the process method which will be used in this research to fabricate the hybrid MMC. Then, in Chapter 4, the result and outcomes of the mechanical properties of the hybrid MMC will be discussed. Last but not least, Chapter 5 will conclude the investigation of the research on the fabricated hybrid MMC.

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